Use of popliteal brachial pressure index as a predictor of wound healing after below-knee amputations with absent popliteal pulse

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Received: 13 August 2022
Revised: 27 August 2022
Accepted: 31 August 2022
Published: 05 April 2023

The Egyptian Journal of Surgery 2023, 41:1314–1320

Background
A below-knee amputation is a transtibial amputation that involves removing the foot, ankle joint, and distal tibia and fibula with related soft tissue structures. Several factors are used to determine the appropriate level of amputation that ensures proper wound healing.

Aim
The aim of this study was to determine the reliability of using the popliteal brachial pressure index as a predictor of wound healing after below-knee amputations with absent popliteal pulse. Popliteal brachial pressure index is the ratio of systolic blood pressure measured at the popliteal artery to that measured at brachial artery.

Patients and methods
This is a prospective observational cohort study. A total of 58 patients undergoing below-knee amputation secondary to chronic ischemia and peripheral arterial disease between November 2019 and January 2022 in Ain Shams University hospitals were included. The study assessed the popliteal brachial pressure index as a predictor of wound healing in below-knee amputations with absent popliteal pulse. The Fisher exact test, analysis of variance test, and the receiver operating characteristic curve were used, with significance defined as *P* value less than or equal to 0.05.

Results
The study was done on 58 patients, comprising 22 (37.9%) females and 36 (62.1%) males, with age ranged between 48 and 80 years and a mean±SD age of 63.97±6.44 years. Healing was primary in 44 (75.86%) patients, delayed in nine (15.52%) patients, and failed in five (8.62%) patients. The cutoff value of popliteal brachial index (PBI) above which below-knee amputation with absent popliteal pulse can be done with high incidence of primary healing was more than 0.48; this value was statistically reliable (*P*=0.0017). However, the cutoff value of PBI above which below-knee amputation with absent popliteal pulse can be done with prediction of primary or delayed healing was more than 0.43, but it was not statistically reliable (*P*=0.0872).

Conclusion
PBI can reliably be used as a predictor for primary wound healing in patients undergoing below-knee amputation with absent popliteal pulse secondary to chronic limb ischemia.

Keywords:
below-knee amputation, chronic limb ischemia, popliteal brachial index, wound healing

Egyptian J Surgery 2023, 41:1314–1320

1110-1121

Introduction

A below-knee amputation is a transtibial amputation that involves removing the foot, ankle joint, and distal tibia and fibula with related soft tissue structures. It is the most commonly performed amputation [1].

Indications for below-knee amputation include gangrene of several toes extending to or beyond the adjacent metatarsal lesion and showing no tendency to demarcate, spreading gangrene of the foot with or without associated gangrene of the heel or ankle, spreading gangrene of several toes associated with uncontrollable infection of the foot, and failure of a transmetatarsal or syme amputation [2].

Contraindications to below-knee amputation include extensive gangrene and infection of the leg with absence of the femoral pulse at the groin, gangrene of the foot associated with irreducible flexion contracture of the knee joint, and recent acute occlusion of the femoral or iliac artery with inadequate collateral supply at below-the-knee level [2].

Below-knee amputations have three major advantages over above-knee amputations: lower mortality rates, preservation of the knee joint with the prospect of rehabilitation, and minimal stump pain [2].

Four techniques for below-knee amputation are available, and choosing one of them depends on the specific use and the surgeon's personal experience. The important features of these procedures are as follows: use of anterior and posterior myocutaneous flaps, either unequal or equal; use of long posterior myocutaneous flaps, use of equal medial and lateral flaps (skew flaps); and use of osteomyoplasty [3].

The level of amputation is determined by a balance between the natural tendency to try to save as much as possible of the extremity and the surgeon's need to be sure that the amputation will heal at the chosen level. The surgeon's goal is to avoid an inappropriately high level of amputation and revision of an amputation to a higher level [4].

It is usually necessary to rely on combined clinical, noninvasive, and arteriographic findings for determining the level of amputation. Clinical evaluation consists of detection of the most distal pulse level, skin viability, nutritional changes, physical signs of ischemia, and skin temperature. Noninvasive procedures include arterial duplex, which provides data about patency of major arteries and velocities of blood flow. Arteriography can indicate the amount of collateral flow [5].

Aim

The aim of this study was to determine the reliability of using the popliteal brachial pressure index as a predictor of wound healing in below-knee amputations with absent popliteal pulse.

Popliteal brachial pressure index is the ratio of systolic blood pressure measured at the popliteal artery to that measured at brachial artery.

Patients and methods

This is a prognostic observational single-arm cohort study, in which we use the popliteal brachial pressure index as a predictor of wound healing in below-knee amputations with absent popliteal pulse. The study included 58 patients undergoing below-knee amputation with absent popliteal pulse secondary to chronic ischemia and peripheral arterial disease from November 2019 to January 2022 in Ain Shams University hospitals, with postoperative follow-up for 12 weeks, and the outcome measured is the healing of below-knee amputation wound. The inclusion and exclusion criteria were as follows.

Inclusion criteria

(1) Patients undergoing below-knee amputation secondary to chronic ischemia and peripheral arterial disease.
(2) Patients with intact ipsilateral femoral pulse, confirmed by Doppler or arterial duplex.
(3) Patients with clinically absent popliteal pulse.
(4) Patients with popliteal artery pressure equal to or more than 50 mmHg [6–9].
(5) Patients' acceptance and ability to give informed consent.

Exclusion criteria

(1) Patients undergoing below-knee amputation owing to causes other than peripheral arterial disease (trauma, tumor, etc.).
(2) Patients with clinically absent ipsilateral femoral pulse.
(3) Patients with clinically palpable popliteal pulse or with normal triphasic flow on popliteal artery by arterial duplex.
(4) Patients with no detected flow on popliteal artery by Doppler or arterial duplex, or with popliteal artery pressure less than 50 mmHg [6–9].
(5) Anemic patients (Hb $<$10 g/dl) and patients with hypoalbuminemia (serum albumin $<$3 g/dl).

All patients who met those criteria and accepted to sign consent for this study were included and proceeded to the following diagnostic measures were included.

Full detailed clinical history was taken from all patients.

Personal history, including habits of medical importance (smoking, alcohol drinking, and intravenous drug addiction); family clinical history of vascular diseases such as cerebrovascular disease or PADs; clinical history, including the evaluation of cardiovascular risk factors and comorbidities; vascular symptoms of lower limbs such as claudication pain or rest pain; different comorbidities, such as diabetes mellitus, hypertension, dyslipidemia, renal impairment, cerebrovascular disease, and any other medical illnesses; detailed drug history (all daily medications in details); and surgical history (all previous surgeries), especially previous debridement or minor amputations.

Clinical examination was performed for all patients.

General examination, including patients' decubitus, that is,. orthopnea; chest condition, that is, dyspnea;

presence of any disability or previous lost or amputated limb; and presence of pallor or tachycardia. Pulse examination was done, especially in affected limb to confirm presence of palpable femoral pulse and absence of popliteal pulse. Proper examination and assessment of the affected foot were done to confirm nonsalvageability and need for below-knee amputation. Measurement of popliteal artery pressure by applying a cuff to the thigh and brachial artery pressure by applying a cuff to the arm were done, followed by recording of both pressures using Doppler ultrasound and calculation of popliteal brachial index, in a manner that resembles measurement of ankle brachial index.

Routine preoperative laboratories were ordered for all patients.

Kidney function tests, liver function tests, full blood count to exclude anemia, coagulation profile (INR and aPTT), and serum albumin were done.

Preoperative general investigation was ordered for all patients.

ECG and ECHO for cardiac patients to assess the cardiac condition, pulmonary function test for patients with COPD, and thyroid profile for hypothyroid patients were done.

Preoperative diagnostic methods for PADs were done for all patients.

Arterial duplex was done for all patients preoperatively, commenting on degree and percentage of stenosis, site and type of the lesion, and presence of distal run off.

Operative technique

All amputations were performed by vascular surgery consultants and specialists in Ain Shams University hospitals. All amputations were done using the long posterior myocutaneous flap technique. A Redivac suction drain was placed in all stumps and was removed 48 h after operation if there was minimal output. Wound closure was performed in layers with a vertical mattress technique using nonabsorbable sutures, which were routinely removed on postoperative day 14 if there was no surgical site infection.

Postoperative care

All patients were informed to do wound dressing with betadine every other day, and adequate broad-spectrum antibiotics, antiplatelet (acetyl salicylic acid), and vasoactive drugs (Naftidrofuryl) were prescribed for all patients. Instructions for follow-up were given.

Follow up

Patients were followed up for 12 weeks, and the outcomes were primary healing, delayed healing, or failed healing. Healing within 4 weeks without additional debridement or revision was considered as 'primary healing.' Disturbed wound healing that lasts beyond the fourth week but eventually leads to closure of the wound within 12 weeks was classified as 'delayed healing.' Amputations complicated by wound necrosis or severe infection, leading to subsequent above knee amputation, were classified as 'failed healing' [10].

Data management and analysis

The collected data were revised, coded, tabulated, and introduced to a PC using Statistical Package for the Social Sciences (IBM SPSS statistics for windows, Version 25.0. Armonk, NY: IBM Corp). Data were presented, and suitable analysis was done according to the type of data obtained for each parameter.

Descriptive statistics

(1) Mean and SD for parametric numerical data.
(2) Frequency and percentage of nonnumerical data.

Analytical statistics

(1) Fisher's exact test was used to examine the relationship between two qualitative variables when the expected count was less than 5 in more than 20% of the cell.
(2) Analysis of variance test was used to assess the statistical significance of the difference between more than two study group means.
(3) The receiver operating characteristic (ROC) curve provides a useful way to evaluate the sensitivity and specificity for quantitative diagnostic measures that categorize cases into one of two groups.

Results

The study plan was accepted by the ethical committee of Ain Shams University Hospitals, and it was held at Ain Shams University Hospitals. All patients included in the study signed an informed consent form. The study was conducted on 58 patients, comprising 22 (37.9%) females and 36 (62.1%) males, with age ranged between 48 and 80 years and a mean±SD age of 63.97 ± 6.44 years. The amputation was left sided in 32 (55.17%) patients. A total of 26 (44.83%) patients had previous debridement/minor amputation in the affected limb.

All patients had chronic limb ischemia with nonsalvageable feet, either due to severe infection or foot ischemia or both. Arterial duplex done preoperatively for all patients showed patent CFA with variable degrees of SFA and/or popliteal artery disease, which ranged from diffuse arterial disease to total occlusion.

Healing was primary in 44 (75.86%) patients, delayed in nine (15.52%) patients, and failed in five (8.62%) patients.

No statistically significant difference among the three groups regarding demographic data, clinical data, and comorbidities (Tables 1 and 2).

The mean±SD popliteal brachial index (PBI) was 0.62 ± 0.13 in the primary healing group, 0.51 ± 0.09 in the delayed healing group, and 0.51 ± 0.22 in the failed healing group. The duration of healing in delayed group ranged from 5 to 11 weeks, with mean±SD of 7.67 ± 2.00 (Table 3).

There is a statistically significant difference in PBI among the three outcome groups.

The cutoff value of PBI above which below-knee amputation with absent popliteal pulse can be done with high incidence of primary healing was calculated using the ROC curve (Fig. 1 and Table 4).

The cutoff point was more han 0.48 with 95% confidence interval and *P* value 0.0017 (statistically

Table 1 Demographic data of the studied patients

	Failed		Delayed		1ry Healing		ANOVA		
	Mean	SD	Mean	SD	Mean	SD	*F*	*P* value	Sig.
Age	65.20	4.49	62.89	6.70	64.05	6.66	0.21	0.807	NS
	n (%)		*n* (%)		*n* (%)		Test of sig.		
Sex									
Male	3 (60.0)		5 (55.6)		28 (63.6)		Fisher exact test	0.897	NS
Female	2 (40.0)		4 (44.4)		16 (36.4)				
Smoking									
No	3 (60.0)		6 (66.7)		27 (61.4)		Fisher exact test	1	NS
Yes	2 (40.0)		3 (33.3)		17 (38.6)				

ANOVA, analysis of variance.

Table 2 Clinical data and comorbidities of the studied patients

	Failed [*n* (%)]	Delayed [*n* (%)]	1ry healing [*n* (%)]	Fisher exact test	
				P value	Sig.
DM					
No	0	1 (11.1)	7 (15.9)	1	NS
Yes	5 (100.0)	8 (88.9)	37 (84.1)		
HTN					
No	1 (20.0)	2 (22.2)	14 (31.8)	0.890	NS
Yes	4 (80.0)	7 (77.8)	30 (68.2)		
IHDs					
No	3 (60.0)	6 (66.7)	24 (54.5)	1	NS
Yes	2 (40.0)	3 (33.3)	20 (45.5)		
CKD/ESRD					
No	4 (80.0)	7 (77.8)	36 (81.8%)	0.890	NS
Yes	1 (20.0)	2 (22.2)	8 (18.2)		
CVS					
No	4 (80.0)	7 (77.8)	34 (77.3)	0.898	NS
Yes	1 (20.0)	2 (22.2)	10 (22.7)		
Other illness					
No	4 (80.0)	8 (88.9)	33 (75.0)	1	NS
Yes	1 (20.0)	1 (11.1)	11 (25.0%)		
Side					
Left	3 (60.0)	5 (55.6)	24 (54.5)	1	NS
Right	2 (40.0)	4 (44.4)	20 (45.5)		
Prev. debridement/amputation					
No	3 (60.0)	3 (33.3)	26 (59.1)	0.858	NS
Yes	2 (40.0)	6 (66.7)	18 (40.9)		

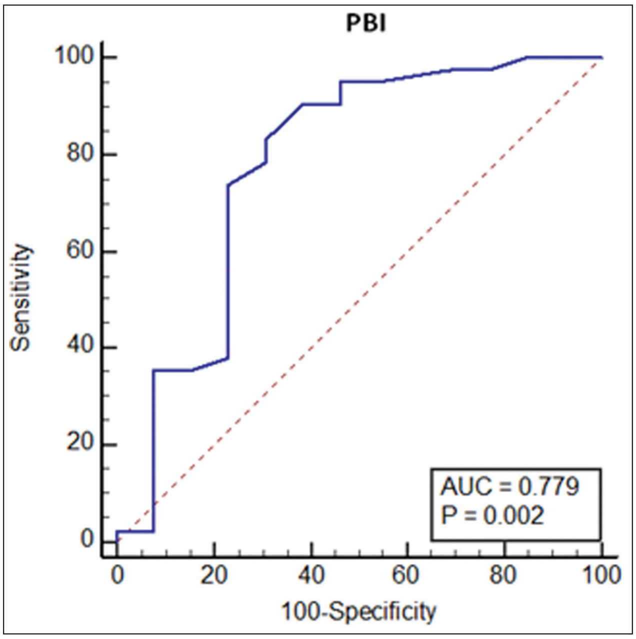
CKD, chronic kidney disease; CVS, cerebrovascular stroke; DM, diabetes mellitus; ESRD, end-stage renal disease; HTN, hypertension; IHDs, ischemic heart disease.

Table 3 Popliteal pressure, brachial pressure, and popliteal brachial index among each group

	Failed		Delayed		1ry healing		ANOVA		
	Mean	SD	Mean	SD	Mean	SD	F	*P* value	sig.
Brachial pr.	142.00	7.58	137.78	9.39	137.61	10.37	0.43	0.652	NS
Popliteal pr.	74.00	31.50	70.00	11.95	84.88	18.36	2.51	0.091	NS
PBI	0.51	0.22	0.51	0.09	0.62	0.13	3.18	0.0496*	S
Duration in weeks			7.67	2.00					

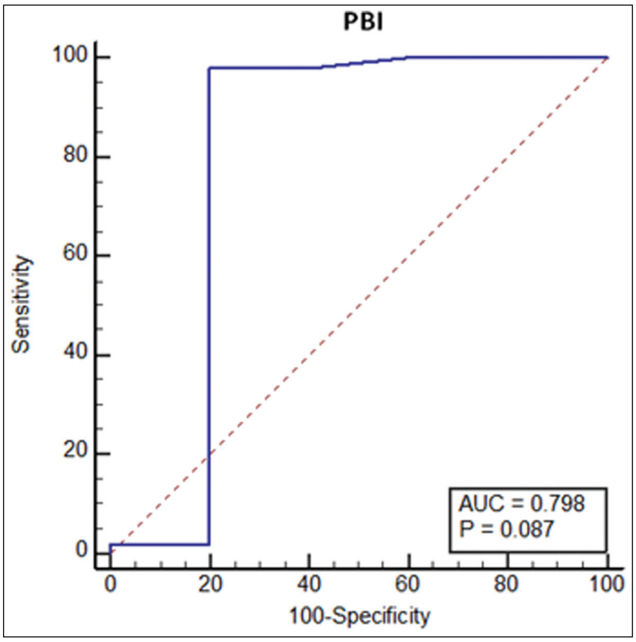
ANOVA, analysis of variance; PBI, popliteal brachial index. *P* value >0.05: nonsignificant; *P* value <0.05: Significant.

Figure 1



ROC curve of PBI to predict primary healing. PBI, popliteal brachial index; ROC, receiver operating characteristic.

Figure 2



ROC curve of PBI to predict delayed and primary healing. PBI, popliteal brachial index; ROC, receiver operating characteristic.

Table 4 Receiver operating characteristic curve of popliteal brachial index to predict primary healing

AUC	95% CI	*P* value	sig.	Cutoff point	Sensitivity	Specificity	+PV	–PV
0.779	0.647 to 0.880	0.0017	S	>0.48	83.33	69.23	89.7	56.2

–PV, negative predictive value; +PV, positive predictive value; AUC, Area under the curve; CI, confidence interval.

Table 5 Receiver operating characteristic curve of popliteal brachial index to predict delayed and primary healing

AUC	95% CI	*P* value	sig.	Cutoff point	Sensitivity	Specificity	+PV	–PV
0.798	0.668 to 0.894	0.0872	NS	>0.43	98	80	98	80

+PV, positive predictive value; AUC, area under the curve; CI, confidence interval; –PV, negative predictive value.

significant); sensitivity and specificity were 83.33 and 69.23%, respectively. Thus, this value is reliable.

The cutoff value of PBI above which below-knee amputation with absent popliteal pulse can be done with prediction of primary or delayed healing was calculated using the ROC curve (Fig. 2 and Table 5).

The cutoff was more than 0.43, with 98% sensitivity and 80% specificity; however, the *P* value of 0.0872 was not statistically significant. Thus, this value is not reliable as a predictor of wound healing.

Discussion

There are many parameters to predict wound healing after below-knee amputations in patients with peripheral arterial disease and chronic limb ischemia. In our study, we used the popliteal brachial pressure index as a predictor of wound healing after below-knee amputations with absent popliteal pulse. The results yielded three outcomes, which are primary healing (75.86%), delayed healing (15.52%), and failed healing (8.62%).

The cutoff value of PBI above which below-knee amputation with absent popliteal pulse can be done safely with high incidence of primary wound healing was more than 0.48, and this was a statistically reliable value (P=0.0017), whereas the cutoff value to predict delayed or primary healing was more than 0.43, but it was statistically not reliable (P=0.0872); thus, a PBI more than 0.48 is highly predictive for primary wound healing.

PBI was previously used as a prognostic predictor in some interventions, such as predicting response to lumbar sympathectomy in patients with severe lower limb ischemia [11]; however, its use as a predictor of wound healing in below-knee amputations was so limited, instead other parameters that assess hemodynamics and tissue perfusion were repeatedly used.

Alfawaz *et al.* [12] used popliteal artery patency as an indicator of ambulation and healing after below-knee amputation in vasculopaths. They found that popliteal artery patency carries high probability for wound healing; however, healing occurred in some patients with diseased or occluded popliteal artery.

Junaidi *et al.* [13] used Doppler ultrasonography indicators including peak systolic velocity, volume flow, arterial diameter, and distal artery spectral waveform as predictors of wound healing following below-knee amputation, and they concluded that Doppler ultrasonography can be used as a predictive pre-amputation testing modality to predict wound healing after below-knee amputation.

Wu *et al.* [14] made a series of 210 peripheral arterial disease below-knee amputations and used many predictors for healing, one of which was the presence of popliteal artery pulse. A total of 108 (51%) patients had clinically absent popliteal pulse; however, 94 (87%) of 108 patients achieved wound healing.

Evans *et al.* [15] used absolute popliteal artery pressure to predict wound healing in below-knee amputations. Healing at the below-knee level was attained in 87% of patients with a popliteal pressure of 60 mmHg or more.

McCollum *et al.* [6] and Dean *et al.* [8] used ultrasonically derived arterial pressure in determination of amputation level and found that a thigh pressure of 50 mmHg correlates well with success of below-knee amputation.

O'Dwyer and Edwards [16] assessed the association between lowest palpable pulse and wound healing in below-knee amputations. They found that absent femoral pulse resulted in 79% failure rate of below-knee amputations; this rate was reduced to only 29% when femoral pulse is palpable.

Lepäntalo *et al.* [17] used segmental blood pressure to predict healing of below-knee amputations. They found that healing occurred in all limbs with calf systolic pressures of 68 mmHg or more and distal thigh systolic pressures of 100 mmHg or more.

Pollock and Ernst [18] used Doppler pressure measurements in predicting success in amputation of the leg. They found that if blood pressure is greater than 55 mmHg at the knee, satisfactory healing will follow amputation. Barnes *et al.* [19] used preoperative Doppler ultrasonic assessment of below-knee (BK) arterial signals and systolic blood pressures to predict healing of below-knee amputations. Failure of amputation occurred in four of 16 limbs with BK pressures less than 70 mmHg. Healing occurred in all 32 limbs with BK pressures greater than 70 mm. Absence of a detectable arterial signal below the knee may be an indication for initial above-knee (AK) amputation.

Besides the use of absolute pressure, clinical assessment and other hemodynamic parameters, other modalities were used to predict wound healing.

De Silva *et al.* [20] used laser-assisted fluorescence angiography to predict wound healing and found that it can accurately predicts stump healing.

Another widely used parameter of below-knee amputation healing is transcutaneous oximetry ($TcPO_2$). Arsenault *et al.* [21] published a systematic review of 31 studies including 1960 amputations and found that TcPO2 more than 40 mmHg carries high incidence of wound healing and low risk of healing complications.

Adera *et al.* [22] used laser Doppler skin perfusion pressure (LD-SPP) to predict amputation wound healing. The study showed that an LD-SPP value of 30 mmHg or greater had a negative predictive value (healing occurred) of 100% in below-knee amputations.

If we considered the available literature and our findings, PBI is an easily performed test that can be widely and reliably used as a predictor of healing. It is superior to laser-assisted fluorescence angiography, LD-SPP, and even $TcPO_2$ in being a bedside test that does not need any special equipment or facilities. It is also superior to measurement of absolute arterial pressure at the level of calf, knee, or thigh, as it is affected by variations in systemic blood pressure. However, no single parameter can be used solely to predict wound healing in below-knee amputations, and a combination of different parameters is better used.

Limitations of our study include inability to measure popliteal artery pressure in morbidly obese patients where a cuff could not be applied to the thigh and in patients with heavily calcified noncompressible popliteal artery where Doppler signals were still audible at high pressures reaching up to 250–300 mmHg, thus hindering calculation of PBI. Moreover, failure of healing and need for subsequent above-knee amputation in some patients was due to infection rather than ischemia.

Conclusion

Popliteal brachial pressure can be used as a predictor of wound healing after below-knee amputations with absent popliteal pulse secondary to chronic limb ischemia, with a reliable cutoff value more than 0.48. However, multicenter studies with a higher number of patients are necessary for further evaluation of PBI use as a healing predictor.

Financial support and sponsorship

Nil.

Conflicts of interest

All authors have no conflict of interest. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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